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BEST PRACTICES IN SHIFT HANDOVER COMMUNICATION: MARS EXPLORATION ROVER SURFACE OPERATIONS

Bonny Parke, Ph. D.[1], Andrew Mishkin[2]

[1] San Jose State University Foundation/NASA Ames, MS 262-4, NASA Ames Research Center Moffett Field, CA 94035-1000, BParke@mail.arc.nasa.gov
[2] Jet Propulsion Laboratory, MS 301-250, 4800 Oak Grove Drive, Pasadena, CA 91109-8099 Andrew.H.Mishkin@jpl.nasa.gov

ABSTRACT

During its prime mission, Mars Exploration Rover (MER) had many shift handovers in its surface operations. Because of the increased rates of accidents and errors historically associated with shift handovers, MER Mission management paid close attention to shift handovers and, when possible, developed them in accordance with best handover practices.

We review the most important of these best practices, and include a generic "Checklist for Effective Handovers" to aid in the development of handovers.

We present charts that depict structured information transfer across shifts. These charts show personnel schedules, meetings attended, handovers, and hand-offs on both the MER and on the earlier Mars Pathfinder Mission (MPF). It is apparent from these charts that although the MER Mission had a much larger number of surface operations personnel than MPF (approximately 300 vs. 178), and had three shifts instead of two, that it used many of the successful MPF communication strategies. Charts such as these can be helpful to those designing complicated and unique mission surface operations.

1. BACKGROUND

1.1 Shift Handover-Related Accidents and Error Rates

Accidents, incidents, and errors are related to shift handovers in many high-risk domains. Among the accidents is the 1988 Piper Alpha Disaster, an off-shore oil platform in the North Sea which exploded and then burned, causing 167 deaths [1]. In 1991 in the US, Continental Express Flight 2574 crashed in a cornfield outside Eagle Lake, Texas, killing all 14 people on board [2]. In both cases, miscommunications during shift handover were causal factors. Many other shift-related accidents have been reported [3,4].

In dynamic industries, errors and accidents occur disproportionately after shift handover. Lardner cites several international studies supporting this finding [5,6,7] including those in industrial settings [8], and off-shore [9] and on-shore oil rigs [10]. Higher error rates also occur in American and Canadian [11] Air Traffic Control in the period after position relief briefings. In one study, a quarter of all operational errors occurred in the first 15 minutes after position relief briefings in Air Route Traffic Control Centers and Terminal Radar Control facilities [12].

2. BEST PRACTICES IN SHIFT HANDOVER

The Europeans have long been at work in this field, and Lardner provides an excellent review of the shift handover literature in European off-shore oil, nuclear industry, and nursing [4]. The guidelines and recommendations in the present paper are based both on this literature and the literature from various American domains such as nuclear power, air traffic control, off-shore oil, spacecraft mission control, and aviation maintenance [13]. A few of the most important best practices are discussed below. The rest are summarized in the check-list for effective handovers which follows.

2.1 Two-way Communication, Preferably Face-to-Face

Face-to-face handover is a best practice that is agreed upon in all guidelines and reviews of the literature and is aimed for in most domains studied [5,14,15,16]. The reason is that handover errors are due to differences in the mental models of the outgoing worker and the incoming worker [17,18]. Two-way communication enables the incoming worker to ask questions and rephrase the material to be handed over, so as to expose these differences [17,19, 20]. Face-to-face handovers enable gestures, eye contact, tones of voice, degrees of confidence, and other redundant and rich aspects of personal communication to be utilized in conveying possible different mental models [21,22].

2.2 Face-to-Face Handovers with Written Support

Face-to-face handovers are improved if they are supported by structured written material—e.g., a checklist of items to convey, and/or a position log to review. Written material introduces redundancy in the verbal handover, which, as Lardner points out, reduces the risk of erroneous communication [5,23]. It also allows one to specify ahead of time those aspects of the communication that are most important and should not be left out.

Face-to-face handovers with written support have been shown to reduce errors in aviation maintenance compared to written handovers with verbal communication filtered through a supervisor [24]. Face-to-face handovers with written support are standard operation procedures in many high-risk domains, e.g. in U. S. nuclear power plants [14] and air traffic control [15]. Guides to handover procedures in U. S. aviation maintenance also include face-to-face handovers at the work site (sometimes called "walk-downs") supported by written material [16]. Hour-long face-to-face handovers with written support are scheduled for mission control for both the Shuttle and International Space Station [25].

2.3 Content of Handover Captures Intent

Handover communication works best if it captures problems, hypotheses, and intent, rather than simply lists what occurred. Recent research indicates that perception and memory are organized by hierarchical goal representations and that these representations in turn drive narrative comprehension, memory and planning [26,27]. Two nursing studies demonstrate that simply listing historical events (either verbally or in written material) is not as effective in conveying accurate mental models of the situation as describing problems, hypotheses, and intent [28,29]. Grusenmeyer also attributes shift handover communication errors to a listing of work completed rather than giving a predictive diagnosis of the situation [17].

CHECKLIST FOR EFFECTIVE SHIFT HANDOVERS

The following check list contains additional best practices distilled from both the European and American literature cited earlier.

1) Is sufficient schedule over-lap time and distraction-free space allocated for effective one-on-one, face-to-face shift handovers?
2) Is sufficient time and distraction-free space allocated for necessary group handovers?
3) Are handovers face-to-face, or if not, is there an opportunity for two-way communication regarding tasks, i.e., can questions be asked? For example, prior arrangements can be made to have questions answered via other technologies (phones or emails) or third parties.
4) Is time allocated and are resources provided for the outgoing shift to prepare any handover material?
5) Are the necessary information sources readily accessible to the incoming worker?
6) Is time allocated and are resources provided to develop written support of handovers, such as structured shift handover worksheets with specific questions or a list of material to be covered?
7) Was this written material developed with the input of those who will use it?
8) Was the written material evaluated by the workers in a trial period with the opportunity to recommend additions and/or deletions?
9) Does the written material have some blank fields for workers to describe unusual occurrences?
10) Does the written material demand inclusion of relevant information as ascertained by worker input, critical incident analysis, and/or careful consideration of risks associated with not handing over the material in question?
11) In both written and verbal descriptions of tasks and occurrences, is there an effort to capture problems, hypotheses, and intent, rather than simply listing what occurred?
12) If there are multiple tasks or sources that must be reviewed before coming onto a shift, is there a check list to insure that all will be accomplished?
13) Are the shift handover procedures written up?
14) Are the shift handover procedures specifically trained?
15) Are shift handovers periodically monitored?
16) Is handing over known to be an equal responsibility of both incoming and outgoing worker?
17) Is there an effort to promote a culture where communication mistakes are expected, and efforts are made to avoid them or mitigate their consequences when they occur? In this type of culture, phrases such as "Good catch!" are heard.
18) Are workers alerted to the necessity for lengthier and more thorough handovers in abnormal operations, when either person is new at the job, and when the one taking over has been away from work for a few days?
19) Are days off staggered in a team to preclude their all returning at once?
20) Are computer databases, word processing programs, and other software tools used when possible to reduce handover workload?
21) Are handover databases searchable?
22) Are handovers seen not only as error-prone, but as sometimes potentially beneficial? Problems encountered in the first shift can be viewed by a second pair of experienced eyes and personnel from both shifts can engage in collaborative problem solving.

4. MER MISSION BACKGROUND

The MER mission landed two robotic rovers on the surface of Mars in early 2004, with the intent of searching for evidence of the past presence of liquid water. The original mission design called for operating these vehicles for 90 Martian days, but as of this writing both rovers remain operational. Due to the inherent

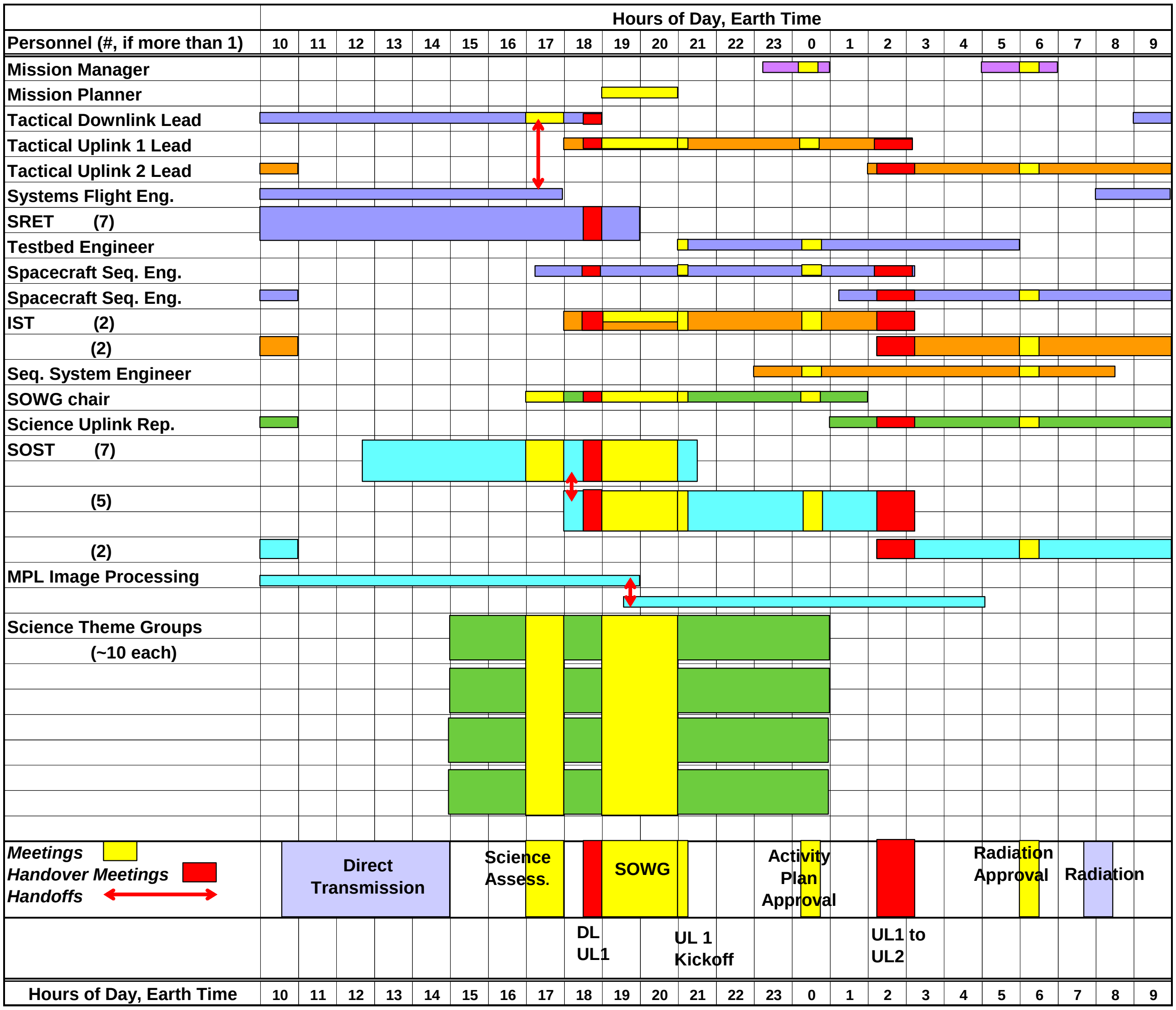

Fig. 1. MER Surface Ops Chart during prime mission, Spirit sols 1 – 85, showing work schedules, meetings, and handovers of surface ops personnel on a typical day. (Since the chart is based on Earth time, the schedule as a whole moves to keep on a rover sleep/wake cycle based on the longer Martian sol.) Work roles are in the left column, with the number of personnel for each role, if more than one, in parentheses. The height of the bar in the chart indicates the number of people involved. Hours of the day in Earth time are on the top and bottom of the chart. Blocks of yellow indicate shared meetings, and blocks of red indicate handovers; hand-offs are depicted by a red arrow. The names of events are in the second and third row from the bottom. Purple blocks indicate communication from the rover to Earth (Direct Transmission--DT) or from Earth to the rover (Radiation). See acronym list at end of paper for further details.

uncertainty in the Martian surface environment and the need to respond to new data acquired by the rover, the MER operations system was designed to be reactive, such that data downlinked from the rover each Martian afternoon would drive a tactical "overnight" planning process that would assess the state of the vehicle and determine the rover's activities for the next Martian day. During the early prime mission, this operations process required approximately 18 hours and three shifts to generate the commands to be uplinked to the vehicle. The duration of this process and the solar-powered design of the rovers required the teams to work on a schedule synchronized to the Mars clock (1 Mars day = 24 hours 40 minutes). As the mission continued beyond its design lifetime, a combination of team experience and continuing ground tool automation permitted reductions in the process duration, eventually decreasing the number of required handovers. Also, after about Spirit sol 85, MER personnel stopped working a Mars-time schedule and began working a single-shift sliding Earth-time schedule. The most important handovers currently occur from one day to the next.

5. STRENGTHS OF THE MER SURFACE OPS DESIGN DURING PRIME MISSION

5.1 Placement of SOWG Meeting

It can be seen in Figure 1 that the Science Operations Working Group (SOWG) meeting is attended by nearly all personnel working the first two shifts. The placement of this meeting at this juncture is heritage from the Pathfinder Mission (Figure 2). The SOWG is responsible for deciding tactical rover operations. Among its members are scientists from the science theme groups: Geology, Mineralogy/Geochemistry, Atmospheric Science, Rock/Soil Physical Properties, and Long-Range Planning. It is at the SOWG meeting that the scientists and engineers weigh the various proposals for the next sol's rover activities and decide on one. The meeting is filled with discussions of scientific intent, eloquently argued and debated. It is this type of face-to-face interaction and discussion of intent, with opportunity for questions and feedback, which has been shown in the handover literature to reduce chances of misunderstandings. The discussion is backed up with written minutes from the SOWG documentarian which are available online. Figure 1 shows that the bulk of the personnel, those from the 1st shift, are scheduled (on this particular day) from 1500 to 0100 (10 hours). The smaller second shift is scheduled from 1800 to 0315 (9 hrs. & 15 minutes). There hence is about 3 hours overlap time. With the exception of the 8 member Spacecraft/rover engineering team (SRET), and the MIPL engineers, most personnel from both shifts attend the two hour SOWG meeting (here depicted from 1900 to 2100). This means that about 66 people are in attendance (assuming 10 members per science theme group). Hence there is widespread exposure to the information presented at this meeting.

5.2 Placement of First to Second Shift Handover

Important communication takes place between those who have received and analyzed the data which has been downlinked from the rover and instruments on the previous sol, and those who will prepare the uplink commands for the next sol. Both the Spacecraft/Rover Engineering Team (S/RET), the flight/vehicle hardware and software specialists, and the Science Operations Support Team (SOST), which includes the onboard instrument specialists, are involved in this handover. The placement of this handover *before* the SOWG meeting is beneficial. Again, this placement is Pathfinder heritage (Figure 2). The incoming uplink (UL1) team (second shift) has been briefed face-to-face by the outgoing downlink (DL) team on the previous sol's downlink data before the SOWG meeting. Then during the SOWG meeting, the outgoing downlink (DL) team (first shift) is there to give face-to-face input to the larger group, which the incoming uplink (UL1) team (second shift) will hear *again*. Both DL and UL1 teams will also hear the scientists' discussion on what the rover's activities will be on the next sol. Before the downlink personnel go home, then, they will have an idea about possible sequences to be radiated, as well as the scientific intent and rationale for them. This prepares the DL team for the next sol's downlink material.

5.3 Second to Third Shift Handover

A new third shift was added to the MER Mission, one not present in the MPF Mission. This new MER handover is not only on the critical path but is late, closer to radiation., so it is extremely important that information be transmitted accurately. As can be seen from Figure 1, the new handover, from the second to third shift (UL1 to UL2), is an hour long formal face-to-face handover. During this meeting, the third shift team is given the context for the radiation plan, and both second and third shift team members review the validated plan. This handover can be seen as having benefit (as well as risk) in that there are fresh eyes reviewing the radiation plan.

5.4 Around-the-Clock Tactical Mission Leadership

Figure 1 shows around-the-clock coverage between the Tactical Leads (DL to UL1 to UL2). Moreover, these leads have adequate overlaps in schedules with each other (between ½ to 1 hour), with handovers formally scheduled. Also, these leads participate in all major meetings and can therefore be relied upon as a human repository of information on main events of the day. Hence there is always a face-to-face back up for written records, which are available online.

5.5. Online Written Material

Among the online written material used on MER is the structured handover between third and first shift. Although much of it is now automated for MER, this rover uplink report is heritage from MPF. On MPF it described the scenario for the sol, the details of the sequence, a log of science-related commands, and anything else the uplink team wanted the downlink personnel to know. This online handover worked very well, and was put to the test when MPF went to a sliding Earth-time schedule during sols 31-85 (Figure 3). During this time it was the only contact between the first and second shift. Therefore, the form and content of this uplink report has been historically validated.

6. CONCLUSION

Although the MER prime mission had three shifts and many more surface ops personnel than earlier missions, effective communication between shifts was made possible by (1) building on successful communication strategies from the MPF Mission and (2) ensuring that handover communication conformed to best practices where possible. Some of these best practices include

- lengthy face-to-face meetings or handovers allowing for questions and feedback,
- a large proportion of MER personnel witnessing discussions of intent regarding each sol's activities,
- strategically placed handovers to insure redundancy of information transferred,
- written documentation online for backup, and
- the presence of around- the-clock tactical mission leadership.

Charts showing structured information transfer between surface operations teams and shifts are helpful in highlighting vulnerabilities in complicated mission scenarios.

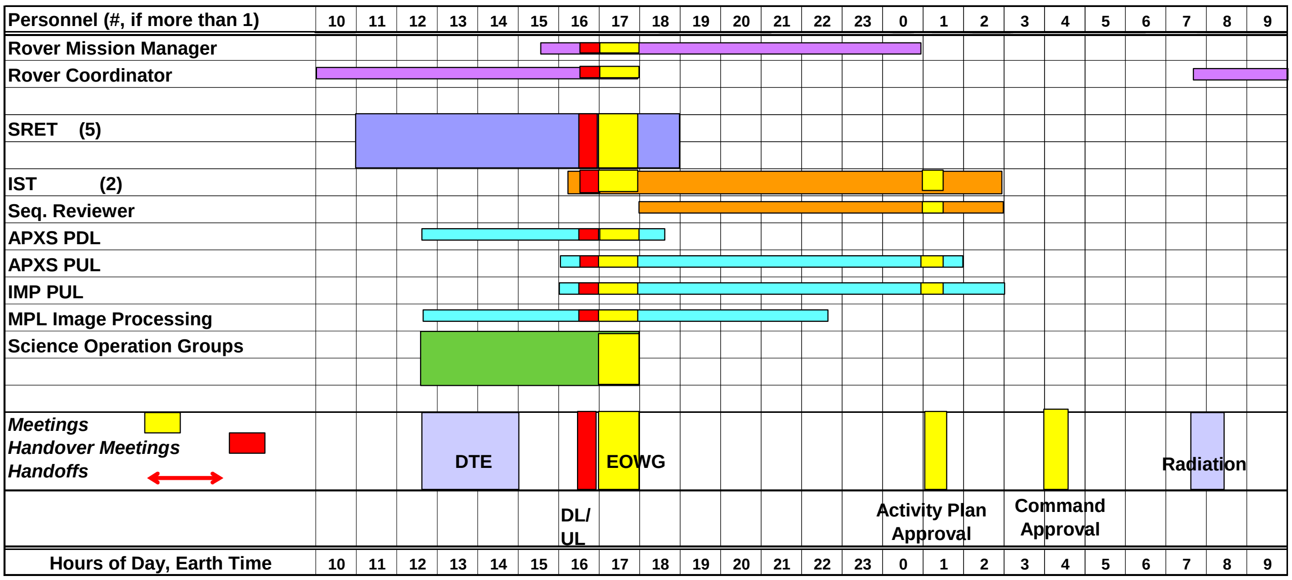

Fig. 2. Mars Pathfinder (MPF) Surface Ops Chart during prime mission on Mars-time schedule, sols 1 – 30, showing work schedules, meetings, and handovers

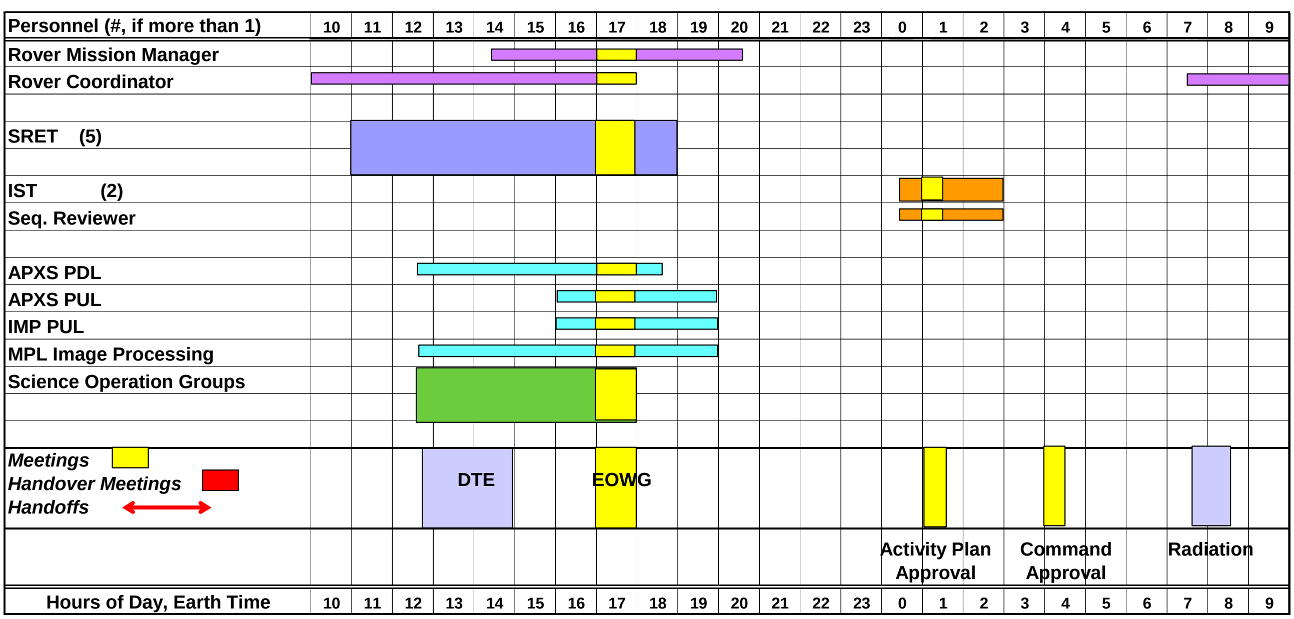

Fig. 3. Mars Pathfinder (MPF) Surface Ops Chart on sliding Earth-time schedule, from Sols 31 – 85, showing work schedules, meetings, and handovers

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Acronyms

DL Downlink
APSX Alpha Proton X-Ray Spectrometer
EWOG Experiment Operations Working Group, the MPF equivalent of the MER SOWG
IMP Imager for Mars Pathfinder (lander camera)
IST Integrated Sequencing Team (integrates instrument activity sequences recommended by the SOWG with the flight/vehicle sequences recommended by the S/RET and is responsible for command sequence generation and validation)
MER Mars Exploration Rover Mission
MIPL Multimission Image Processing Laboratory (processes mission data into science image/data products)
MPF Mars Pathfinder Mission
NTSB National Transportation Safety Board
PDL Payload Downlink personnel
PUL Payload Uplink personnel
SOST Science Operations Support Team (includes instrument specialists—PDLs & PULs)
SOWG Science Operations Working Group (responsible for deciding tactical rover operations & includes scientists from science theme groups: Geology, Mineralogy/Geochemistry, Atmospheric Science, Rock/Soil Physical Properties, and Long-Range Strategic Planning)
SRET Spacecraft/Rover Engineering Team (flight/vehicle hardware & software specialists)
UL1 Uplink 1st (Team)
UL2 Uplink 2nd (Team)

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